THE SUN AND STARS[1]

V.

Metallic Prominences

VERY impressive indeed are the phenomena when we pass to that other class representing prominences no longer of the quiet sort. These are at times observed shooting up almost instantaneously—the exact rate of motion I will state by and by—to enormous heights; and not only are they seen to shoot up into the atmosphere with very great velocity and with every indication of the most violent disturbance, but the alteration in the lines of hydrogen in the spectrum indicates most violent lateral motions. These phenomena unfortunately have been called eruptions, and, as it very often happens, when we get a word like that coined it means more than it is intended to mean by the author of it; and more or less on the strength of this word "eruption," we have theories trying to explain these prominences on the idea that they are ejected, possibly from a volcano—a real solar volcano—at some distance below the photosphere. I think we have no right to call them eruptions at all. In the first place they are not like any volcanic eruption that man has ever seen.

When we get the chromosphere agitated preparatorily to one of these tremendous outbursts—one of these metallic prominences, as they are called—the lines which we see are different from those in the table which I have given. The Italian observers, to whom we are indebted chiefly for our knowledge on this part of the subject, have recorded three lines, which they call the "elementary metallic prominence spectrum." These are—

4943 No Fraunhofer lines corresponding.
5031 ,, ,, ,,
5315·9 = 1474

Although these energetic prominences are eventually very often full of lines of various vapours these three lines always precede them when the action commences. There is one point about this matter to which I must call attention, and that is that of these three lines one—the 1474 line—is not the line with the same name to which I have already drawn your attention, and about which we know absolutely nothing, but it is a line of iron almost coincident with it, which the temperature of the spark brings out, though it is invisible in the arc. The other two are lines which do not even appear amongst the Fraunhofer lines at all, and about which, therefore, we know nothing. We have means, both by actual observation in the case of the uprise of the prominences into the solar air and in the change of the wave-lengths of the lines in the case of any lateral motion, of determining how fast these violent prominences rise and are driven by solar winds. Well, these metallic prominences have been seen to mount upwards at the rate of 250 miles a second, that is very nearly 1,000,000 miles an hour; so that, if these gases continued their flight they would reach the top of the solar atmosphere, if the solar atmosphere were 1,000,000 miles deep from the top down to the photosphere, in about an hour's time. There are indications that these prominences, instead of rising vertically, as we may imagine them to do, are at times shot out sideways—almost tangentially. In that case, of course, the spectroscope enables us to determine the velocity. 100 miles a second, either towards or from the eye, is by no means an uncommon velocity, and there are also indications that, in the neighbourhood of the photosphere where these enormous prominences take their rise, vividly incandescent hydrogen at a considerable pressure is rushing up from the interior part of the sun.

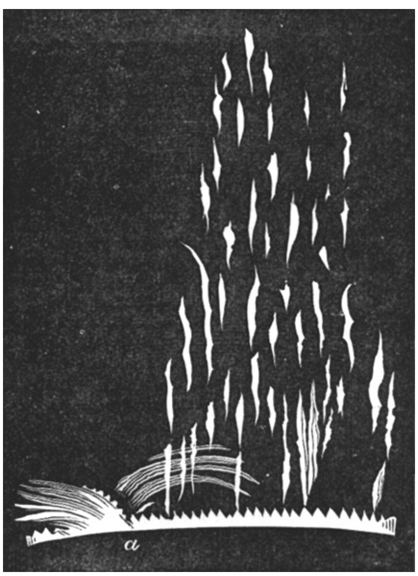

FIG. 15.—Metallic prominence, Young. Rate of ascent 400,000 miles an hour.

[1] A Course of Lectures to Working Men delivered by J. Norman Lockyer, F.R.S., at the Museum of Practical Geology. Revised from shorthand notes. Continued from p. 502.

In the case of some of these violent prominences the spectrum at the base appears to be full of lines, but we know enough about the subject now to know that many, if indeed not most, of those lines are not Fraunhofer lines at all, not lines with which we are familiar, but new ones. In fact, the same thing happens in the prominences as happens in the spots. To show that this is so I again refer to some very important work done by Prof. Young in the United States some years ago. He went to a station in the Rocky Mountains, at a height of 8000 feet, to observe these prominences. Of course the higher we go the purer the air, and the better we can see. As the result of one month's work he brought back a very valuable catalogue of lines which he had seen in such prominences as I have attempted to describe.

Let us consider one particular substance. It is always well in these matters to be as definite as possible, and if the prominences contained that particular substance, say, for instance, barium, in the same conditions in which we find it on this earth, we should imagine that the spectrum of barium in the prominence would be very much like the spectrum of barium in the electric spark. To see whether that was so or not, what my assistants and myself did was this. We prepared a map showing the lines of barium over a long reach of the spectrum, and we drew the lines so that the longest represented the strongest according to our highest authority in these matters, Prof. Thalèn. Alongside of these we made another map showing the particular lines which had been seen by Prof. Young, and we assumed that the line which was strongest at the sun would be the line which he would most probably see most frequently, and therefore we made the line which he saw the greatest number of times the longest line. That being premised, you will see there is no relation whatever between these two spectra. In the first place a great number of the lines of barium seen in the laboratory are left out of account altogether in the prominence spectrum, and when the other lines are considered we find that the intensities in the sun are quite different; and that, I may say, is a very fair indication of what as a matter of fact we have observed with regard to a number of these substances. Calcium, iron, nickel, cobalt, and several other metals which we have tested in the same way, give us exactly the same result.

But there is more important work to do than that. Since Prof. Young made those admirable observations in America, the Italian observers, Profs. Tacchini and Riccò, have been observing metallic prominences every day. It has been our duty at Kensington to map every line which these industrious Italian gentlemen have observed ever since 1871, and in these maps, as in those of spot-spectra, we have the lines of the various elements seen in the sun, in the arc, and in the spark. Now, of all those lines, we only get a very small number in the prominences. In the case of iron, for instance, in the F—*b* region, we may say there are only two lines; one iron line was left out by mistake by Prof. Thalèn in his map of the solar spectrum, and the Italian observations of the sun suggested to us at Kensington that Thalèn, at Upsala, had made an omission in the spectrum of iron. This we found to be the case. All the other lines are clean swept out of the record. We get none of them in the spectrum of prominences.

At a certain date, I believe about the end of December 1873, the lines in question suddenly ceased to appear in the spectrum of prominences. The Italian observers, who had observed them constantly day by day for three years, suddenly found them gone, but other new lines were seen. I shall show by and by that there was a very good reason why that should have happened. But the important point now is that it really did happen.

The Relation between Spots and Prominences

We are now in a position to discuss the relation between the spots and the prominences. We are already familiar with the lines affected in spots. We have now seen the lines affected in prominences. Are they the same? To investigate this question maps have been prepared in exactly the same way as those to which reference has already been made. We have at the top the lines affected in spots, and at the bottom the lines affected in prominences. In hardly any case are the lines of any one vapour widened in the spots the same as the lines brightened in the prominences.

There is another very interesting fact which is also seen alongside of this; if we regard the lines seen widened in the spots, or that other set of lines seen bright in the prominences, we find, when we come to study the positions of those lines in the spectrum with the positions of the lines of elementary bodies, that in the case of very many of them there are coincidences between the lines of different chemical elements with the dispersion that was employed.

We have learnt since then that the coincidence is not entirely absolute, but whether that be so or not, we have the very extraordinary fact that, while of all the iron lines taken at random the chances of the coincidence of any one line are very small, of iron lines widened in spots, or of iron lines brightened in prominences, the chances of coincidence are something like ten to one.

In that way you see we make a considerable difference between the lines of iron which are affected in the lower reaches of the solar atmosphere, whether we are dealing with the phenomena of spots or of prominences, and the lines of iron which are dropped out.

These discussions to which I have referred have led us to make the following statements with regard to prominences, on all fours with the statements already made regarding spots:—

General Statements

(1) The chromospheric and prominence spectrum of any one substance, except in the case of hydrogen, is unlike the ordinary spectrum of the substance. For instance, we get two lines of iron out of 460. Thus we see that the spectrum of a substance in the prominences is very unlike its spectrum out of a prominence, that is, in our laboratories or in a sunspot.

(2) There are inversions of lines of the same elements in the prominences as there are inversions in the spots, that is to say, in certain prominences we see certain lines of a substance without others; in certain other prominences we see the other lines without the first ones.

(3) Very few lines are strongly affected at once, as a rule, and a very small proportion altogether; smaller than in the case of spots.

(4) The prominences are not so subject as spots to sudden changes so far as lines of the same element are concerned.

(5) There is a change in the lines affected according to the sunspot period. This is a point about which I shall have to say something by and by.

(6) The lines of a substance seen in the prominences are those which in our laboratories are observed to be considerably brightened when we change the arc spectrum for the spark spectrum.

(7) None of the lines ordinarily visible in prominences are seen at the temperature of the oxy-hydrogen flame. Some of the oxy-hydrogen flame-lines are seen in the spots, but, as said before, none of these lines have ever been seen in the prominences.

(8) A relatively large number of lines ordinarily seen are of unknown origin.

(9) Many of the lines seen are not ordinarily seen amongst the Fraunhofer lines. Some are bright lines.

(10) As in the spots we found that the H and K lines of calcium in the ultra-violet were always bright in the spot-spectrum, the other lines of calcium being darkened and widened; so also it would appear that the lines H and K of calcium are always bright in the prominences in which the other lines are generally unaffected.

(11) Many of the lines are common to two or more elements with the dispersion which has been employed.

A Case in Point

In the region of the spectrum which has been most studied with regard to spots and prominences, are three lines of iron adjacent in the solar spectrum, so close together, that if you see one you are bound to see the other two. A study of these three lines affords a very definite and interesting case, indicating that it is not at all necessary to go over the whole spectrum to see these results. We have those three lines in the solar spectrum of wave-lengths 4882, 4898, and 4923·1. They are seen among the Fraunhofer lines with the intensity shown in the accompanying diagram (Fig. 16). If we photograph the spectrum of the arc very quickly we miss the right-hand member altogether, and get the two left-hand lines alone. If we observe the spectrum of the iron spark with a quantity coil (and a jar) the left-hand member almost disappears. If we use no jar the right-hand member almost disappears. If we use an intensity coil with a jar not only does the left-hand member nearly disappear, but the right-hand member is enormously developed. If we take out the jar we bring about very much the same condition as we have among the Fraunhofer lines. Now, what happens at the sun? The two lines on the left of the diagram have alone been seen widened in spots. The right-hand member has never been

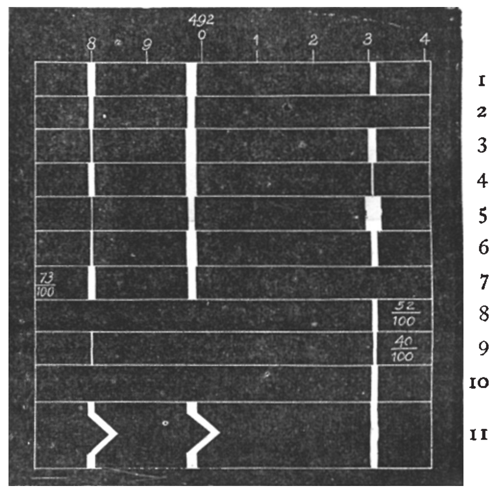

FIG. 16.—Diagram showing the behaviour of three iron lines under different conditions, solar and terrestrial. 1, solar spectrum; 2, arc; 3, quantity coil with jar; 4, quantity coil without jar; 5, intensity coil with jar; 6, intensity coil without jar; 7, spots observed at Kensington; 8, prominences observed by Tacchini; 9, prominences observed by Young; 10, reversed in penumbra of spot observed on August 5, 1872, by Young; 11, motion indicated by change of refrangibility.

seen widened in spots. Contrariwise the right-hand member has been seen in 52 per cent. of the prominences which have been observed by Prof. Tacchini, but the left-hand members have never been seen in any prominence whatever. The last result is this, that in spots the left-hand members have indicated that the spot has been descending at the rate of 50 miles a second, while the right-hand member has shown that the spot is not descending at all—that the vapour is just as quiet as could possibly be expected.

Those are some of the hard facts gathered by the observation of three lines quite close together. During the eclipse of 1882 my chief work was to see what happened to those three lines. What did happen was this: the line seen in prominences was observed 7 minutes before totality began, as a very short bright line close to the photosphere of the sun, whilst the other two lines did not come out until the moment before totality began, and were then very thin and feeble lines at the best, indicating that the absorbing molecules which produce them exist in all probability at a considerable elevation in the sun's atmosphere.

The Corona

We now pass to the inner and outer corona. We are still of course engaged with the question of materials, and may take these two together.

The spectrum of the inner corona indicates that it is chiefly composed of hydrogen. All the hydrogen lines are seen in it, and up to a certain height in it we get the H and K lines of calcium, showing that either calcium, or something that exists in calcium which we cannot get at in our temperature, is there.

When we go further afield into the outer corona we leave behind us most of the hydrogen lines, but one, the green line F, remains for a considerable height side by side with the 1474 line, indicating, as far as we can see where everything is so doubtful, that so far as the gaseous constituents of the outer corona are concerned they consist most probably of hydrogen in a cool form, and this unknown stuff which gives us the line 1474.

With regard to the other materials of the outer corona we know that it contains particles which reflect the ordinary sunlight to us, because in 1871 Dr. Janssen and in 1878 Prof. Barker and others saw the dark Fraunhofer lines in the spectrum of the corona. We must imagine, therefore, that some part of the spectrum of the corona depends for its existence on solid particles which not only give us such a spectrum as the limelight does, but which further have the faculty of reflecting to us the light of the underlying photosphere.

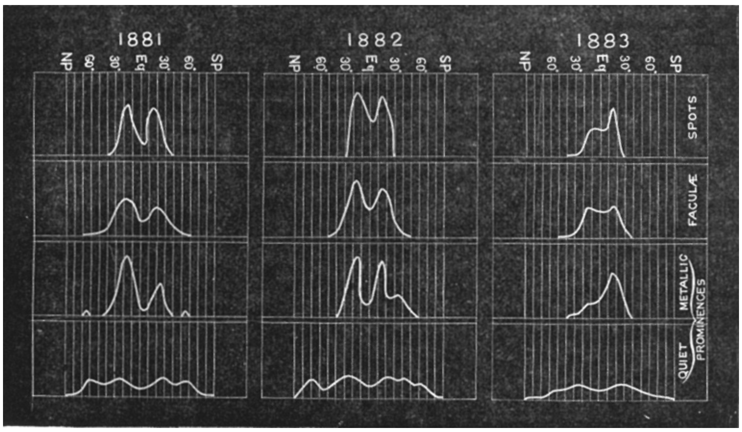

FIG. 17.—Diagram summarising the results of the Italian observations for the years 1881-83.

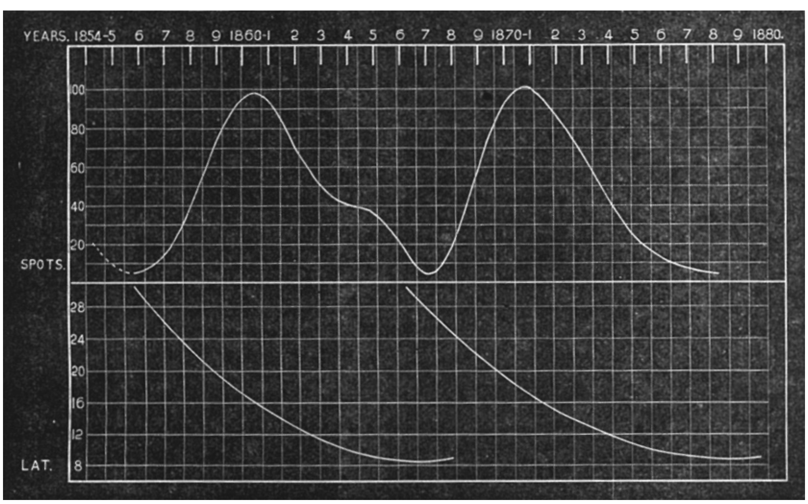

FIG. 18.—Spörer's sunspot curves. The upper one indicates the amount of spotted area in each year; the lower one the mean latitudes of the spots.

It was also put beyond all question in the eclipse of 1882 in Egypt that this corona has another spectrum of its own. I was fortunate enough to see that eclipse under very good conditions, and the spectrum which had been supposed up to that time to be a continuous spectrum only was an integration of a considerable number of spectra. There were bright bands and dark bands from one end of the spectrum to the other, showing that, with these additions, it was no longer continuous in the same way that the spectrum of the limelight is continuous, but that it was probably excessively complex in its origin.

General Connection of the Foregoing Phenomena

We next come to an excessively important point—the connection of the various phenomena which we have now passed under review with each other.

The Italian observers have not only very carefully observed the prominences from day to day, but they have observed spots and the other phenomena which require continuous investigation. The accompanying diagram puts together in a very convenient form much information which we want at the present moment. The information extends over three years, so that we have not merely to depend on the result of one year's observation. The curious-looking hieroglyphics, which are called curves, have a very simple explanation. In the middle of each of these series E stands for the equator, and right and left of that we have vertical lines giving every 10° of latitude from the equator to the poles south or north for each year. The height of the curves from the base-line represents the number either of spots, faculæ, metallic or quiet protuberances seen each year. The spots in the year 1881 had their maximum in latitude 20° N. and 12° S. There were no spots either north or south of latitude 40°, and there were very few spots indeed near the equator of the sun. In 1882 the conditions are a little changed. There are some spots near the equator, and the maximum of spots now is 18° N., and there are more spots this year than there were last, because the curve is higher. Going on to 1883 the maximum of spots has changed from the north of the equator to the south, and in latitude 15° S. we have a reduced maximum, whereas in the northern hemisphere we get very nearly the same quantity in latitudes 10° and 20°. The other curves may now be compared with these, and the point of enormous importance is this, that the maxima faculæ and the metallic prominences agree absolutely in position with those of the spots.

When and where the spots are at the maximum the faculæ and the metallic prominences are at the maximum. If the maximum changes from north to south, as it does, in the spots, it changes from north to south in the metallic prominences, and from north to south in the faculæ; so that were we dependent on these diagrams alone, representing three years' work, we should be driven to the conclusion that there is absolutely the most tremendous and important connection between spots, the metallic prominences, and the faculæ; and not only that, we reach finally the fact of the wonderful localisation of these phenomena upon the sun. The spots are never seen north or south of 40°. They are invariably seen in smaller quantity at the equator; similarly the faculæ do not go very much further than 40° north or south, and their minimum is also at the equator. The metallic prominences also never go very much beyond the spot region, and they also have a minimum at the equator.

But when we pass to the protuberances of the quiet sort that is not so. They extend from one pole of the sun to the other, so that whatever it may lead us to, we are bound to consider that there is the most intimate connection between spots, metallic prominences, and faculæ, and that there is a great difference between the metallic prominences and the quiet ones. That

is a result to have arrived at of the very first order of importance.

I have next in connection with that diagram to give another which we owe to the labours of a German observer, Prof. Spörer. Not only have we to accept the fact that these important solar phenomena are limited to certain zones, but we have to study that fact in connection with another, that though all of them vary very violently, they all have what is called a cycle, and the cycle affects the particular zone of the sun on which they appear. Here a sunspot curve, as it is called, writes out for us in a graphic form the quantity of spotted area on the sun from year to year. It begins at 1867, and ends at 1878. This curve means that when the curve is at its highest, we get the greatest number of spots, or the greatest amount of spotted area on the sun's surface. At one place we get a very sudden increase of the spotted area. The curve is almost like a chalk cliff, it goes straight up, but it does not come so straight down. The curve from the minimum of spots on the sun to the maximum is very much steeper than that from the maximum to the next minimum. The sunspot period on an average is one of about eleven years, and it may be said, though I do not want the term to be misunderstood, to represent the seasons on the sun, because when we get that curve low, we see the sun for days together without any spots on it at all. When we get to the highest part, of course there is the greatest number of spots on it.

In connection with that period then, which, as it is good for spots, must also be good for faculæ and for metallic protuberances, after the results obtained by the Italian observers, it is most interesting to see in further detail whether there is any difference in the part of the sun thus affected. The two lower curves show us that when there is the smallest number of spots on the sun—when there is a sunspot minimum—the spots that appear are seen in a high latitude, and that latitude goes on decreasing and decreasing regularly and gradually until we get, at the next minimum, a real over-lapping of two perfectly distinct spotted areas. When we have the maximum period of sunspots, the latitude of the sunspot zone is between 8° and 10°, but it gets much lower than that when the period is closing, and even before one period has closed another one has begun in a higher latitude, so that the swirl in the solar atmosphere seems to begin in a high latitude—say 30° or 35°, or thereabouts—and very soon gets into full swing in latitude between 10° and 12°, and then it very gradually dies away until spots and metallic prominences and faculæ cling pretty near to the equator, and then we get a new wave of activity, beginning again in a high latitude, as is indicated by the beginning of the second curve.

Drawings made by Mr. Carrington a good many years ago show this result in another form, which emphasises the enormous difference in the amount of spotted area, as it is called, at the maximum and minimum time. Another diagram gives the results of the last eleven years' work at Greenwich, where they have been computing the positions of the spots obtained on their photographs and on the photographs which the Solar Physics Committee receives from India. This gives the history of the sunspot period in rather a different way; we begin in the year 1873, and end in the year 1884, and the curves represent the amount of faculæ, of penumbræ, and umbræ. Here again we get both faculæ, penumbræ, and umbræ increasing towards the maximum period, and it is seen that when we come to discuss photographs instead of depending on eye-observations, as the Italians did, we still find that the faculæ and the spots vary together. Another diagram shows another important matter. We are now discussing at Kensington the results obtained from the photographs from several points of view. One point of view is this. It seemed hard, after all the trouble taken to observe latitudes, that all spots north and south of the equator should be lumped together in a mere statement of spotted areas. The two upper curves in the diagram represent the spots north and the spots south; and an important thing which comes out of this is that the curve representing the greatest amount of spotted area north and that representing the greatest amount of spot area north and south do not go together. We do not get the greatest amount of spots north and south of the equator at the same time. A peak in the south curve is in two or three cases associated with a valley in the north curve.

J. NORMAN LOCKYER

(*To be continued.*)

THE CORRELATION OF THE DIFFERENT BRANCHES OF ELEMENTARY MATHEMATICS[1]

AMONG the permanent acquisitions to mathematical science secured within the last half century, within the limits of those branches with which our Association concerns itself, two (I conceive) stand out as pre-eminent in their far-reaching and all-pervading consequences.

These are the firm establishment as distinct entities of two concepts, which have been fixed for all the future of science in the terms *Energy* and *Vector*, and the development of the groups of ideas and principles which cluster around each.

The term *Energy* indeed, and the great principle of the *Conservation*, or (as I prefer with H. Spencer to call it) *Persistence*, of Energy, the establishment of which will live in the history of science as the great achievement of the central part of the nineteenth century, have a scope far beyond the purely mathematical treatment of dynamics and the allied branches of physical sciences. They, the concept and the principle, have already profoundly modified the views of the physicist as to the natural laws with which he is concerned, and are destined to form the starting-point and firm foundation for all his conquests in the future. But no less is it true that the conception of energy, while it has naturally arisen out of the higher mathematical treatment of dynamics, has necessitated a very material recasting of that treatment in its most elementary, as well as in its more advanced, stages, if it is to bear any fruitful relation to physical science in general. This recasting of elementary dynamics, if not yet fully and satisfactorily effected in most of the text-books which still remain in use, in which the notion of energy is brought in rather as the "purple patch" than inwoven into the whole texture of the robe in which the subject is clothed, is yet, thanks pre-eminently to the teaching of Maxwell, Thomson and Tait, and Clifford, in a fair way for being accomplished.

The influence of the conception of energy is, however, as regards mathematics, rather an influence from without than one from within its peculiar domain.

That which is strictly mathematical in the treatment of any science is not its subject-matter, but the *form* in which that subject-matter must from its nature be expressed. Mathematics, as such, is in fact *a formal* (may I not say *the* formal?) science, concerning itself with the particular matter only so far as that matter necessitates a particular form for its expression. Hence the recurrence of the same formulæ and mathematically the same propositions in different branches of science, so that, to take elementary instances, a proposition in geometry may be read off as a proposition in statics by substituting forces for lines, or the formula which determines the speed of the centre of mass of two masses having different speeds is also that which determines the temperature resulting from the mixture of two masses of different temperatures.

To this *formal*, or essentially mathematical, part of the exact sciences belongs the conception of a *Vector*, or rather the group of conceptions which cluster around that term. The term itself was introduced by Hamilton in connection with his grand theory of quaternions about forty years since, but the idea had been already firmly grasped and developed so as to afford a complete explanation of the imaginary ($\sqrt{-1}$) of ordinary algebra within the twenty years preceding that epoch. In fact in the year 1845 I myself enjoyed the privilege, as a young student, of attending lectures of De Morgan on this subject, which he afterwards developed in his treatise on "Double Algebra," published in 1849.[2] I think, however, that we may conveniently date from the introduction of the term "*Vector*," which is now the accepted term for any magnitude which besides numerical quantity or intensity has a definite direction in space, the definitive acquisition of this concept with all its consequences to the settled territory of mathematical science. The calculus of quaternions indeed, or that part of it which was truly original and due to the genius of Hamilton alone, involving the conceptions of the products and quotients of vectors in three-dimensional space, is doubtless beyond the range of what now can be, or within the near future is likely to be, regarded as elementary mathematics; but the notions of vector addition and subtraction

[1] A paper read before the Association for the Improvement of Geometrical Teaching by the President, R. B. Hayward, F.R.S. (see NATURE for January 21, p. 277). We print the address in the hope that a discussion of some of its principles may ensue.

[2] Sir W. R. Hamilton's Lectures on Quaternions were published in 1853.